Sheila Morrison - [Fwd: Draft subsidence report for your review] *OK*

0 0 3 8

From: Mark Reynolds <mreynolds@etv.net>
To: Pete Hess <petehess@utah.gov>
Date: 8/1/2006 11:25 AM
Subject: [Fwd: Draft subsidence report for your review]

Here is a copy of the Maleki report. I have requested two changes to it as stated below.

" I have ready your report and there are two pages I have comments on.

The first one is on page 15 where the report says "Subsidence calculations ... were completed for **two** longwall blocks", it then lists three blocks, is the two supposed to be a three?

The second one is on page 24 in the last paragraph. The reports states "C. W. Mining has not observed surface cracking above the existing panels ....". A more accurate statement would be "C. W. Mining has not observed surface cracking above the existing **Wild Horse Ridge** panels ...."

I am working on witting appendix 5Q right now. It will include comments from me addressing some of the issues you outlined in the last TA, and also include both reports from Maleki. I am also changing our proposed subsidence monitoring points based on Maleki's recommendations.

I will be calling you to schedule a time to meet.

-------- Original Message --------
Subject: Draft subsidence report for your review
   Date: Mon, 31 Jul 2006 16:06:02 -0700
 From: H Maleki <maleki.tech@comcast.net>
    To: Mark Reynolds <mreynolds@etv.net>

Mark:

As promised, we have finished your subsidence report by August 1 to give you maximum flexibility. Let me know if you have any changes and I will finalize by the end of the week.

Hamid Maleki P.E.

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PREDICTION OF SURFACE DEFORMATION
RESULTING FROM LONGWALL MINING
OVER THE BEAR CANYON RESERVE

PREPARED FOR

C.W. MINING COMPANY

HUNTIGTON, UTAH

AUGUST 2006

PREPARED

BY

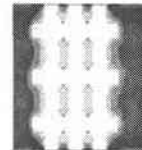## MALEKI TECHNOLOGIES, INC.
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1.0 INTRODUCTION

This report was prepared at the request of C.W. Mining Company for an evaluation of surface subsidence mechanics and determination of typical deformation expected at the Bear Canyon longwall reserve (figure 1) in the C.W. mining operations, located near Huntington, Utah. The study was initiated in response to a deficiency list prepared by resource specialists of the Utah Division of Oil, Gas, and Mining.

Specific objectives were as follows:

- Description of subsidence mechanisms and angle of draw;
- Description of pillar designs developed by C.W. Mining for the multiple seam reserve in the Bear Canyon Study area,
- Calculation of subsidence profiles over the longwall blocks in both Tank and Hiawatha seams using regional subsidence measurement results, and
- General recommendations for surface subsidence monitoring.

The study area is located adjacent to the permitted areas in the C.W. Mining existing room-and-pillar operations located in the Wasatch Plateau Coal Fields of eastern Utah. Longwall mining has been extensively used in both the Book Cliffs and Wasatch Plateau coal fields since its introduction at the Sunnyside mines during 1960's; it is generally considered an environmentally attractive method to mine coal. It minimizes damage to the surface by permitting gradual subsidence of overburden strata over mined-out areas while at the same time satisfying BLM requirements of maximizing economic recovery of coal resources (Maleki and others 2001).

C.W. Mining is planning to mine coal reserves from the study area using the longwall method mostly in the Tank and Hiawatha seams at a typical depth of 800 to 2,000 ft (two limited panels are also envisioned in the Blind Canyon Seam). Existing mine plans call for extraction of the reserve using an extraction height of 5 to 8 ft within longwall panels. Subsidence calculations (consisting of vertical movements and horizontal strains) were completed for three longwall blocks, as illustrated in figure 1.

- Block 1, Tank Seam. For five 500- to-640-ft wide longwall panels retreated from northwest to southeast. Seam thickness varies from 5 to 7.6 ft within this longwall block. We have simulated an average extraction height of 7 ft. This is a conservative and prudent assumption for this study.

- Block 2, Tank Seam. For four 600- to-800-ft wide longwall panels retreated from northwest to southeast. Seam thickness varies from 5 to 8 ft within this longwall block. We have simulated an average extraction height of 7 ft.

- Block 3, Hiawatha Seam. For four 640-ft wide longwall panels retreated from northwest to southeast. Seam thickness varies from 5 to 15 ft within this longwall

block. The extraction height is fixed at 8 ft considering longwall face equipment specifications.

This report is prepared in five sections. After this introduction, the subsidence mechanism is presented in section 2.0, followed in section 3.0 by a description of mining and geologic conditions and subsidence characteristics, including rock mechanics data, subsidence parameters, and a discussion of the conceptual mine layout designs developed by C.W. Mining for multiple seam longwall extraction. Predicted deformation patterns are presented in section 4 using three-dimensional subsidence models. The subsidence monitoring program is reviewed in section 5.

Figure 1. Longwall study area showing the location of two-seam reserves and overburden contours for the Tank Seam. Hiawatha Seam projections are shown in blue.

2.0 SUBSIDENCE MECHANISM

Surface subsidence occurs because of downward rock mass movement caused by the closure and collapse of mined-out excavations. Surface subsidence processes result in both vertical and horizontal displacement of rocks. Two major mechanisms of surface subsidence are associated with mining: formation of sinkholes and creation of troughs.

The type of subsidence mechanism predicted for the study area is the trough-type subsidence. It is characterized by the formation of a relatively smooth basin and is much less damaging than sinkhole subsidence. Sinkholes result from sudden or time-dependent collapse of overburden in localized areas, and these areas can be from several feet to tens of feet in diameter. Based on long-term measurements over the Hanna Basin, Wyoming (Karfakis 1987) and the Colorado Front Range (Matheson and Bliss 1986), researchers have established a relationship between the probabilities of sinkhole subsidence versus overburden depth. A great majority of sinkholes (98% probability) form where depths are less than 160 ft. At typical cover depths of 400 to 2,000 ft over the mains at the longwall project site, the probability of sinkhole occurrence is small, assuming stable "support" pillars.

As longwall operations are initiated in the first panel, roof span increases behind the longwall face until it caves. The roof span varies in mines, but typically ranges from 30 to 200 ft, depending on the strength of the roof rocks. The remaining overburden rocks will remain stable, transferring their load to the face and gate pillars. At some critical face position, the arching and load transfer mechanism collapses, and ground movement expands toward the surface, causing subsidence.

The caving process is associated with fracturing of near-seam strata and settling of overlying rocks. Four zones of movement are associated with subsidence (Peng 1992).

1. *Cave zone—broken and fragmented rocks that fill mined space.* The immediate roof rocks fracture into blocks often controlled by preexisting structure, filling the mined space. Bulking and rotation of individual roof rocks eventually limits the upward growth of failure. The thickness of this zone is estimated to be two to eight times seam thickness, depending on the bulking characteristics of the immediate roof rocks.

2. *Fracture zone—fractured rocks that fail because of shear stresses near the ribs and delamination toward the center of the panel.* This zone is located directly above the cave zone. The strata within this zone move downward, usually in large blocks, but without major rotation, to rest on the caved zone below. The permeability of the rocks is increased within this zone, which is estimated to extend twenty to sixty times seam thickness (Peng 1992) above the mine roof depending on geologic conditions and the strength of the rocks.

3. *Continuous deformation zone—deformation zone from the top of the fractured zone to the surface soils.* The strata flex downward without significant fracturing, gradually settling over the fracture zone. In the absence of soils, this zone extends to the surface,

forming compression zones at the surface to the center of the panel and tension zones at the edge of excavations.

4. *Soil zone*—This zone is an extension of the continuous deformation zone, which, depending on site-specific conditions, generally consists of soils and weathered rocks. Because of the less-brittle nature of soils, tensile cracks associated with transient subsidence may not be detected easily in front of the face and any existing fractures tend to heal quickly. Tensile fractures forming at panel boundaries last longer, but eventually get closed due to caving of fracture walls.

Three subsidence phases are associated with trough subsidence. These are shown in Figure 2.

1. The *subcritical phase* occurs immediately at the beginning when movement is in a small area at the center of the basin.

2. The *critical phase* occurs as the basin area expands when the maximum value of the downward movement is reached at the center. The critical excavation width is generally larger than 1.4 to 1.6 times the overburden thickness and is influenced by position and strength of competent layers within the overburden.

3. The *supercritical phase* occurs as the basin develops a flat bottom. In this phase, the basin area continues to increase with the cave area, but subsidence will remain at the maximum value attained in the critical phase.

Thus, the surface response of longwall mining activity, shown in Figure 2, begins with the subcritical phase, then progresses to the critical phase, and finally, to the supercritical phase. The subsidence process first shows effects on the surface as the upper strata bend, including tension (expansion), which causes near-surface fractures to open up and new ones to be created. Figure 2 shows how the middle portion of the excavation expands as subsidence continues, going through a cycle of, first, tension and then compression, which closes tension cracks. Final subsidence shows an excavation with the middle portions lower in elevation, but back to a near-original state. Areas on the edge of the excavation basin are subjected to tensile strains.

Considering panel width to average overburden depth ratio for the C.W. Mining project area (0.6), these longwall panels are considered to have subcritical widths, and thus the great majority of subsidence is expected during the mining of the second and the third panels. The subsidence process is expected to be mature within 2 years after mining.

Subsidence characteristics for any coal field depends on site-specific geologic conditions and mining practices, including strata competence, geologic structure, topography, extraction height, extraction speed, and mine designs. For instance, rapid changes in topographic conditions are known to influence both naturally occurring and mining-induced rock mass wasting, including sandstone escarpment failure (Maleki and others 2001). The site-specific

subsidence parameters for the Bear Canyon study area are addressed in the following sections using available monitoring results locally and regionally within Utah coal fields.
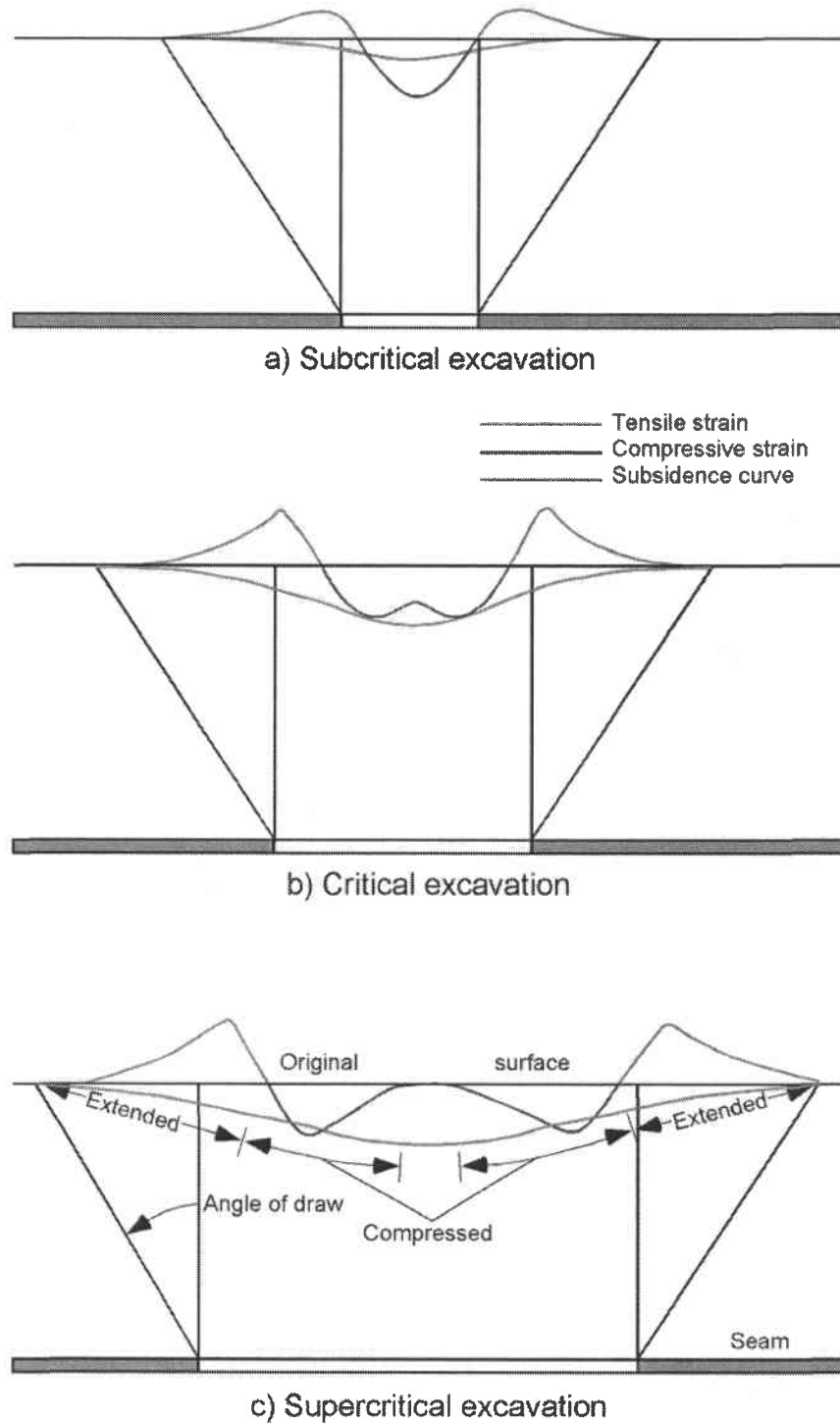
a) Subcritical excavation

Tensile strain
Compressive strain
Subsidence curve

b) Critical excavation

c) Supercritical excavation

Figure 2. The three phases of subsidence development.

3.0 MINING, GEOLOGIC CONDITIONS AND SUBSIDENCE CHARACTERISTICS

3.1 Conceptual Mine Layout Designs

The C.W. Mining Company, in cooperation with MTI engineering staff, implemented geotechnical studies at both Tank and the Blind Canyon seams during the 1990's to study coal seam behavior and support loading during multiple seam pillar extraction (Maleki and others 1999). These studies consisted of underground and surface mapping, installation and monitoring of geotechnical instruments for the evaluation of Mobile Roof Support, and three-dimensional stress analyses. In addition, during 2001, MTI implemented a preliminary escarpment stability evaluation to assess potential pillaring impacts on the stability of the Castlegate Sandstone escarpments at the Wild Horse Ridge reserve. This study utilized a wealth of data collected over both stable and unstable escarpment areas at the neighboring East Mountain and Trail Mountain mines (Maleki and others 2000, MTI 2001).

As illustrated figure 1, C.W. Mining has oriented the longwall panels N55° W and is planning to use three-entry gateroad systems with 30-ft-wide yield pillars (50 ft center-to-center) and 500- to 800-ft-wide panels. This conceptual mine plan is suitable for permitting purposes and additional stress analyses are planned for finalizing mine designs in multiple-seam bump-prone conditions.

At sufficient deviation of 30° from major joint sets (N15° E and N85° E, MTI 2001), the existing mine orientation is beneficial for stability of development workings because it avoids alignment of joints and mine openings.

From environmental point-of-view, MTI considers this orientation effective in reducing the potential for subsidence-related cracking at the surface. Because at panel boundaries, the subsidence cracks generally form near parallel to longwall face and length (Maleki and others 2006), by misaligning the joints and panel orientation, C.W. Mining increases its chances of limiting the number and length of mining-induced surface fracturing at final mining boundaries.

To control gate pillar bumps, C.W. Mining staff has selected yield pillars to reduce strain energy accumulation within the gate pillars. Pillar size was selected on the basis of successful experience in the neighboring longwall operations in the East Mountain and Trail Mountain.

Based on a comprehensive case study by the USBM in 1991, Dyni showed that the narrow 30-ft-wide yield pillars commonly used in the two-entry Utah reserves crushed completely with no influence (or subsidence humps) above the gateroads. Thus the existing layout is also beneficial for reducing surface impacts, although we prefer a two-entry system for coal bump control based on site-specific geotechnical monitoring in the Dugout Canyon Mine (Maleki and others 2003).

3.2 Geology, Rock Strength and Stress Field

The three coal seams of economic interest belong to the Blackhawk Formation which is overlain by the Castlegate Sandstone and underlain by the Star Point Sandstone and the Mancos shale (figure 3). Minable longwall reserves are mostly contained in the Tank and Hiawatha seams with limited reserves also in the Blind Canyon Seam. Tank and Hiawatha seams average 7, and 8 ft in the study area; the Blind Canyon is 7 ft thick.

The overlying cliff forming Castlegate sandstone is a massive cross-bedded unit. It contains occasional thin, interbeds of shale, pebble conglomerate and mudstone. This unit is 170 to 250 ft thick in the area using the corehole data , however, the actual exposed thickness is locally much lower (as low as 50 ft). The Price River Formation consists of numerous beds of cross-bedded sandstones with occasional interbeds of shale, pebble conglomerate, and mudstone.

The Blackhawk Formation is composed of interbedded deltaic mudstone and siltstone and is less resistant to weathering than the neighboring units. It is characterized by alternating slope and cliff forming units. This unit is approximately 750 ft in thickness.

The Star Point Sandstone consists of thick cliff-forming sandstone units separated by shales. It is light colored and is approximately 350 ft in thickness in the study area. The Mancos shale is a blue-grey color marine shale, approximately 1000 ft thick, and is soft and well weathered.

Jointing patterns were mapped at the Castlegate Sandstone horizon and found similar across the study area (MTI 2001). The joint trends are thought to be generally coincident with jointing found in the overlying Price River and underlying Blackhawk Formations and are consistent with the measurements on the Wasatch Plateau (Maleki 1988, Maleki and others 1999). Joints were typically within a few degrees from vertical.

The most pronounced (primary) joint trend typically ranges between N10° E to N20° E (N15° E average). A less pronounced and secondary joint system trending S80° E to S90° E was also observed. This trend appeared to be generally consistent across the study area.

A third joint set was observed infrequently with a N50° E to N55° E trend. This set was only observed in the east near the Fish Creek Canyon. Spacing on this set is estimated to be greater than 10 feet due to its lack of occurrence or expression.

Apparent joint spacing appears to be controlled by confining stress. In outcrop the primary and secondary joints are more apparent and appear closer spaced at or near the points than in head of drainages. Rocks in place often exhibit jointing at 10 - 15 feet spacing, but more broken rocks nearly always showed closer spaced joints.

Faulting is not expected within the longwall reserves (Reynolds 2006).

Site-specific geologic and rock mechanics data are limited, although MTI has collected large amounts of information from adjacent properties. Figure 4 summarize the mechanical properties of coal measure strata at the neighboring East Mountain, compiled by MTI.

Clearly, most overburden rocks are strong and stiff, capable of accumulating large strain energies, which contributes to seismicity.

The researchers from the former USBM and private industry have made a number of stress measurements in mines of Wasatch Plateau, Utah. There are two stress measurements within the close proximity of C.W. Mining operations (figure 5). These measurements confirm that the far-field stress field is unremarkable. The horizontal stress is moderate and is less than 50 percent of the vertical stress magnitude. We anticipate similar stress field at the C.W. Mining operations based on observations of lack of stress-induced stability problems (such as cutters) and an analyses of measurements in the existing reserve (Maleki and others 2000).

3.3 Subsidence Parameters

Subsidence engineering parameters include subsidence factor, angle of draw, angle of critical deformation, and horizontal strain. The subsidence factor is the ratio of maximum measured subsidence to extraction height. Because this ratio depends on excavation width and overburden thickness, it should be measured in supercritical excavations where caving has reached the surface on collapse of the pressure arch.

The angle of draw defines the limit of surface movements beyond the edge of an excavation. It is measured from a vertical line drawn at the panel edge and a line connecting the panel edge to the point of "no" movement on the surface. In practice, the accuracy of surveying equipment defines the point of no movement. This accuracy is usually about 0.1 ft but varies depending on topographic conditions, measurement technique, etc. Angle of critical deformation is similar to the angle of draw, but is measured to a point of critical deformation with respect to existing structures; it is preferred by many practitioners because it avoids the shortfalls connected with the accuracy of surveying equipment. Based on subsidence data from 40 longwall panels, Peng (1992) found that it is 10° less than the angle of draw.

Horizontal strain is the change in horizontal length of the ground divided by the original length of the ground. Positive strain is used here to show tensile strain indicating an increase in the horizontal length of the ground. Compressive strain (negative notation) occurs when the ground is shortened or compressed. Maximum tensile strain is found in supercritical excavation and maximum compressive strain occurs in subcritical excavations. Horizontal strain increases with an increase in extraction height and decreases at greater depths. Surface topography also influences horizontal strain.

The best estimates for the extend and magnitude of subsidence for the C.W. Mining two-seam mining conditions can be obtained by reviewing the results of long-term monitoring in Utah. The USBM implemented a comprehensive subsidence study over the Energy West two-seam longwall reserve from 1978 to 1989. The study monitored surface movements over four Blind Canyon and six Hiawatha panels. The study addressed angle of draw, subsidence factors for single and multiple-seam mining, and critical width. Similar to the Bear Canyon reserve, the mining area was bounded by faults. Maximum subsidence was 68% to 72% of

the extraction height for single and two-seam mining conditions, respectively. This is in general agreement with other measurements in Utah showing a subsidence factor of 70 %. The angle of draw ranged between 25° to 30° for single- and two-seam mining conditions, respectively. This reported maximum angle of draw is higher than average values for the East Mountain (22.5° to 25°, Fejes 1985) but is significantly lower than that reported by the British National Coal Board (NCB 1975).

3.4 Gate Pillar Behavior

Because gate pillar designs may influence surface subsidence, some recent investigations have focused on evaluating subsidence above gate pillars. The Western U.S. measurements show different overburden deformation characteristics influenced by the choice of pillar designs. Based on a comprehensive case study by the USBM in 1991, Dyni showed that the narrow 30-ft-wide yield pillars commonly used in the two-entry Utah reserves crushed completely with no influence (or subsidence humps) above the gateroads. We expect the three-entry yield pillar system at the Bear Canyon Mine to behave similarly. Site-specific calculations to address ground control issues in the three-entry system are forthcoming and will form the basis for petition to switch to a two-entry system.
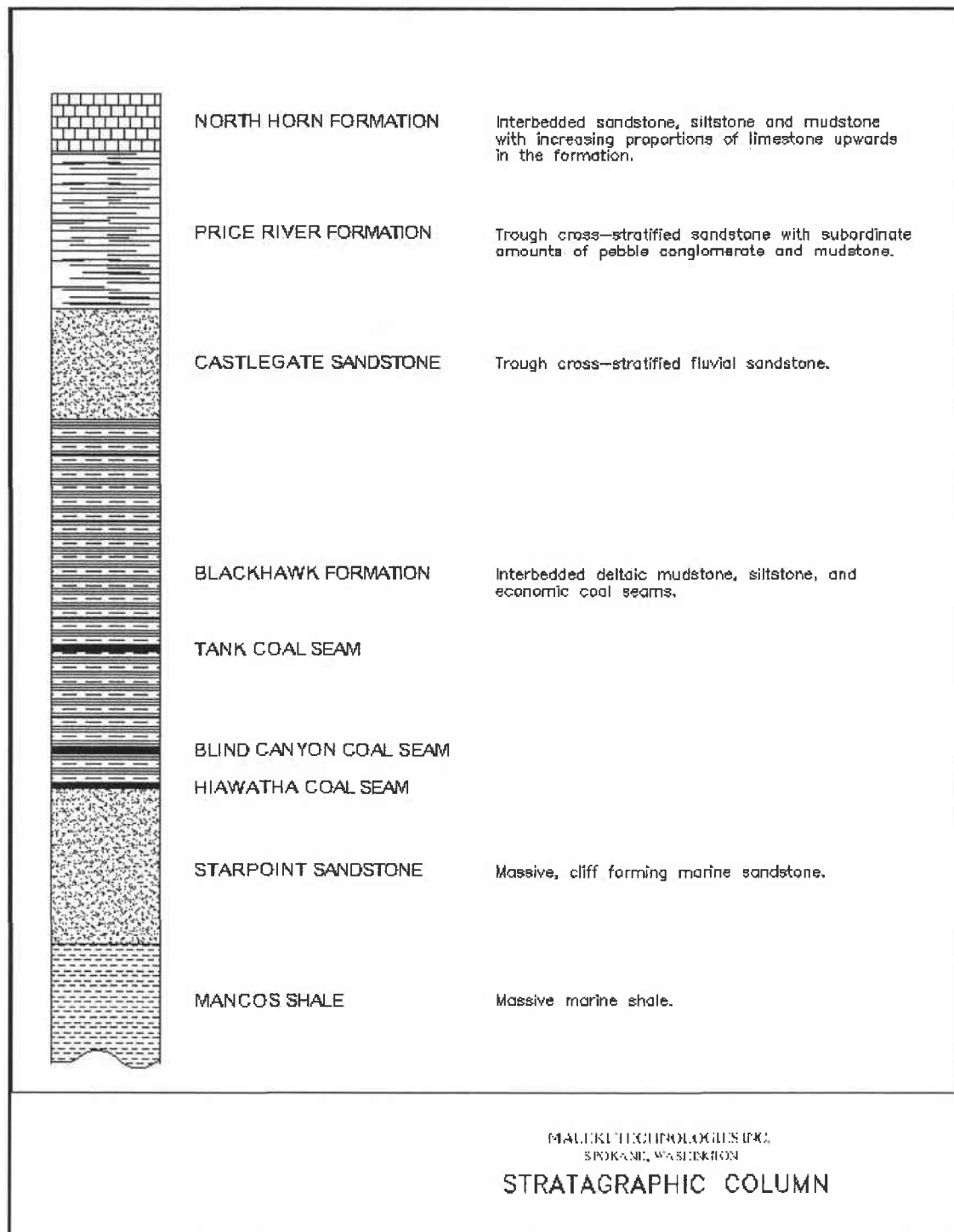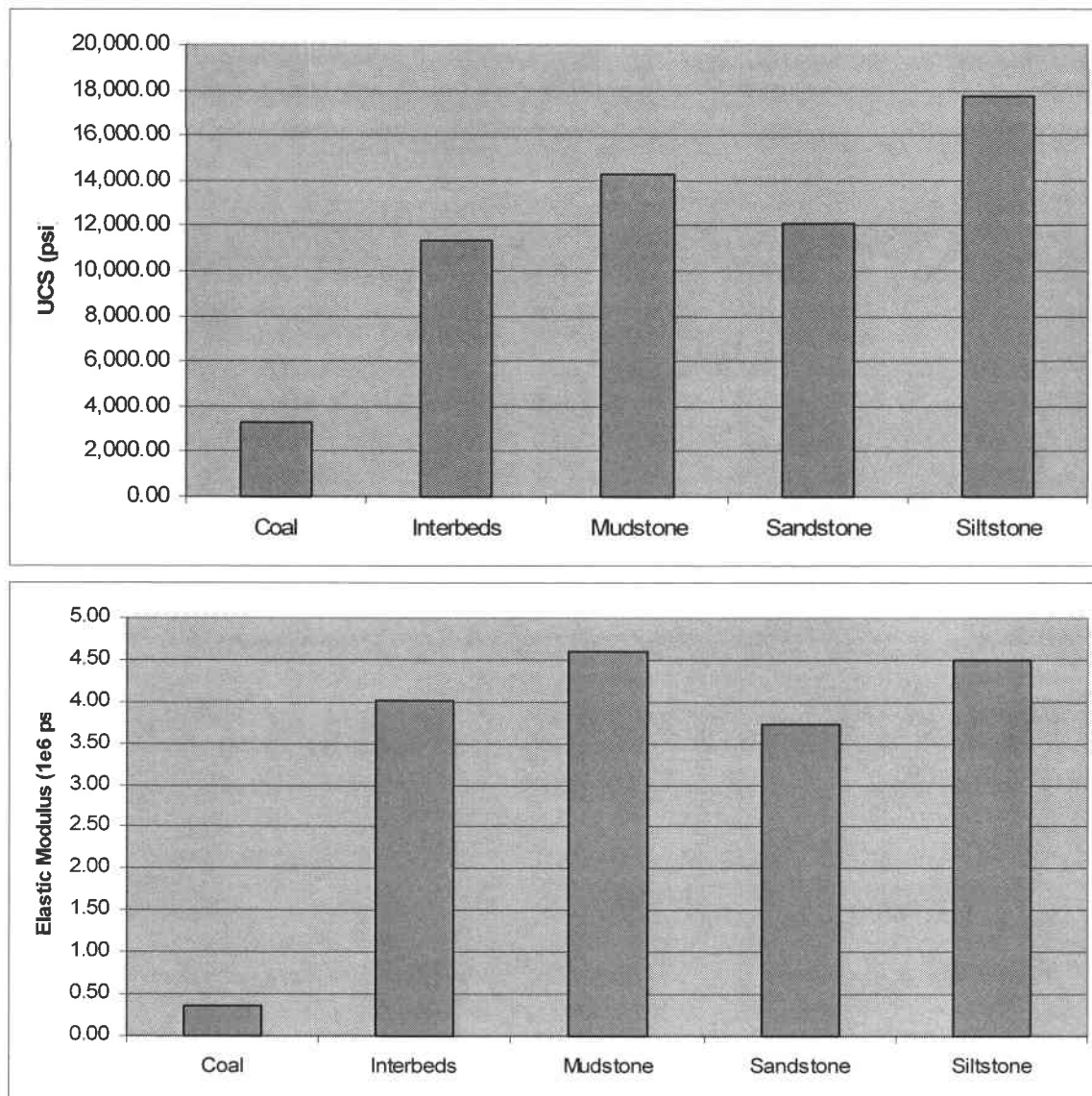
Figure 3. Generalized stratigraphic column.

Figure 4. Histogram frequency diagram of uniaxial compressive strength and Young's modulus, regional data compiled by MTI.
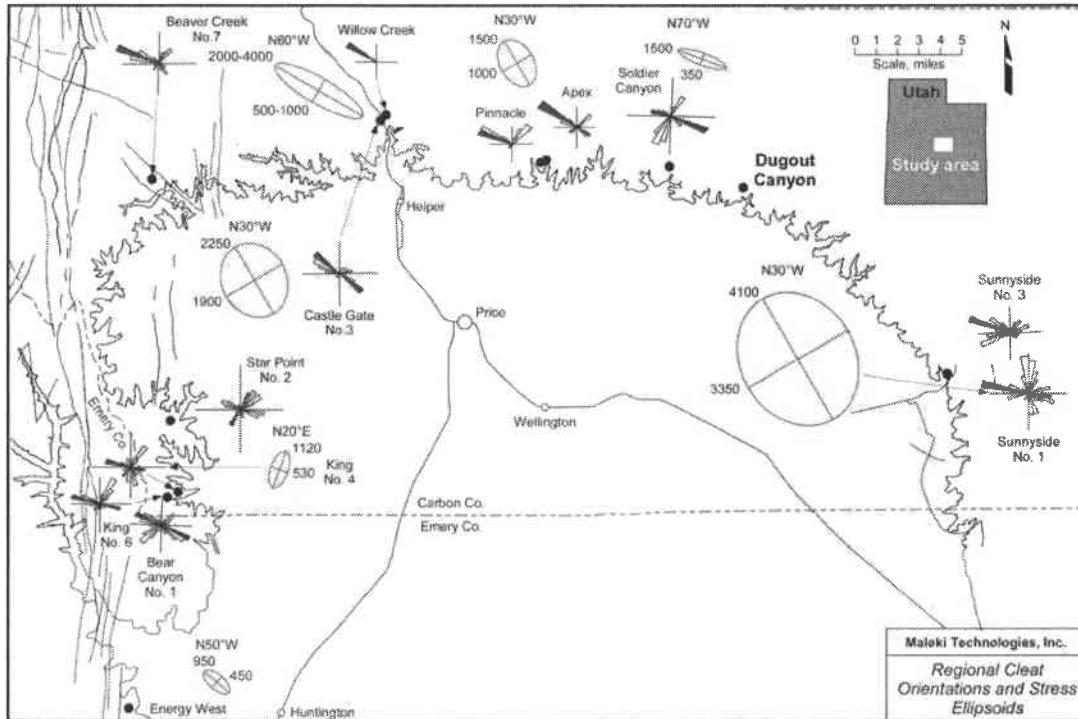
Figure 5. Regional horizontal stress measurements (ellipsoids) and the orientation of cleats in Utah coal fields.

4.0 PREDICTED GROUND MOVEMENTS

4.1 Methodology

Surface subsidence is the readily observable manifestation on the ground surface of the displacement field surrounding the underground portion of the mine. Predicting subsidence magnitude, therefore, constitutes a particular solution of the overall problem of finding the induced displacement field. To study subsidence phenomena and estimate the magnitude of subsidence, a number of empirical, physical, and numerical methods have been used.

Empirical methods, including profile functions, influence functions, and graphical methods were proposed by the British National Coal Board. These methods involve the analysis of existing subsidence from an area to predict future subsidence effects. These methods are based on the mathematical fit of a considerable number of measured subsidence profiles. They apply to geologic conditions in the area where they were developed and require adjustments if they are applied to different strata conditions.

To estimate surface deformation above the proposed longwall panels, we used a three-dimensional influence function method while accounting for site-specific conditions using the subsidence monitoring data from both the neighboring Deer Creek Mine. These methods have become very popular for the prediction of subsidence and surface strains within the last two decades (USBM, 1983; Peng and others 1994; SDPS 2000). They are superior to graphical methods because they can be used to model an entire longwall block while allowing an examination of the sensitivity of results to variations in seam thickness, pillar designs, panel dimensions, and overburden thickness.

These methods rely on the influence of an extracted volume on the displacement components of a remote point on the surface. In the zone calculation method, for example, the circular zone of influence around a point on the ground surface is divided into a number of zones in such a manner that the influence factor of such an area is fixed at a certain value. If the full area of the influence were mined out, the point in question would undergo 100% of maximum possible subsidence. If some portion within the zone of influence were unmined, subsidence would be correspondingly reduced.

Subsidence calculations (consisting of vertical movements, change in surface slopes and strains) were completed for two longwall blocks.

- Block 1, Tank Seam. For five 500- to-640-ft wide longwall panels retreated from northwest to southeast. Seam thickness varies from 5 to 7.6 ft within this longwall block. We have simulated an average extraction height of 7 ft. This is a conservative and prudent assumption for this study.

- Block 2, Tank Seam. For four 600- to-800-ft wide longwall panels retreated from northwest to southeast. Seam thickness varies from 5 to 8 ft within this longwall block. We have simulated an average extraction height of 7 ft.

- Block 3, Hiawatha Seam. For four 640-ft wide longwall panels retreated from northwest to southeast. Seam thickness varies from 5 to 15 ft within this longwall block. The extraction height is fixed at 8 ft considering longwall face equipment specifications (Reynolds 2006).

4.2 Model Calibration

Subsidence predictions were made using a numerical model calibrated with baseline subsidence data from the East Mountain. The long-term surface response to longwall mining in 5E, 6E, 7E and 8E panels was monitored by researchers from the U.S. Bureau of Mines in two phases (figure 6). These panels were mined from May 1974 through January 1983, and subsidence was monitored along five monument lines from September 1979 to June 1983 during phase 1 investigations. Phase 2 results reported by Dyni (1991) include surface response to mining the Hiawatha Seam some 60-ft below extracted 5E through 8E panels in the Blind Canyon Seam.

USBM study reports an average angle of draw of 25 degrees ranging from 16 to 33 degrees, and a final subsidence factor of 67 percent for single-seam mining. Surface effects were described as follows (Fejes 1985):

"There were no visual surface effects within the subsidence area. The local vegetation were not altered, and no surface fissures were detected......"

The results of phase 1 monitoring were used to establish modeling parameters. Figures 7 and 8 present a comparison of measured and calculated subsidence along a north-south monument line during the extraction of each four longwall panels and show good agreement. The subsidence factor increased from .35 during the extraction of 6E to 0.67 after the extraction of 8E. Note that yielding gate pillars used in this longwall block, crushed uniformly, showed no humps in the subsidence trough.

The calibrated version of the model was used to make quantitative predictions of the subsidence expected over the Bear Canyon Mine. The similarities in geology and geometry (depth of cover, face width, yielding gate pillars, and mining height) between the monitored area over East Mountain and the neighboring project area justify the use of the back-analyzed parameters for the predictive model.

Some uncertainty exists for predictions made with the model due to variations in geology and mining geometry, including actual mining heights. Precise estimates of subsidence can only be achieved as site-specific data become available, and mine plans are finalized.

4.3 Results

Figure 9 presents expected subsidence pattern after the extraction of each longwall block and figure 10 the combined two-seam subsidence resulting from extraction of blocks 1, 2, and 3 after the completion of mining in the Tank and Hiawatha seams.

Figures 11 and 12 present both subsidence and surface strain profiles along section A passing through the two-seam longwall extraction zone. Additional results are summarized in table 1 including changes in surface slopes.

Table 1. Predicted subsidence parameters for single and two-seam extraction design options.					
Block	Average mining height, ft	cover, ft	Maximum subsidence, ft	Maximum tensile strain, ft/ft	Maximum slope, percent
1 Tank	7	1,000	4.9	3.2e-3	.7
2 Tank	7	1,000	4.9	3.2e-3	.7
All combined	8	1,300	10.4	3.2e-3	1

Predicted subsidence varies from approximately 4.9 to 10.4 ft for single and two-seam extraction. Using a criterion suggested by Singh and Bhattacharya (1984), tensile strains do not reach levels that could cause localized surface fracturing except at shallow areas (<650-ft cover). This assertion is in agreement with USBM measurements and observations on the East Mountain. The potential for surface fracturing is not higher at the permanent two-seam boundaries because longwall layouts in the Tank and Hiawatha seams are staggered. By not columnizing the longwall extraction areas in multiple seams and by not aligning panel orientation with primary joints, C.W. Mining has reduced the potential for surface fracturing.

Expected surface movement beyond underground mining boundaries varies from 460 ft in block 1 to 750 ft to the northeast where two-seam mining is planned in blocks 2 and 3. Changes in surface slopes are small (approximately one percent).
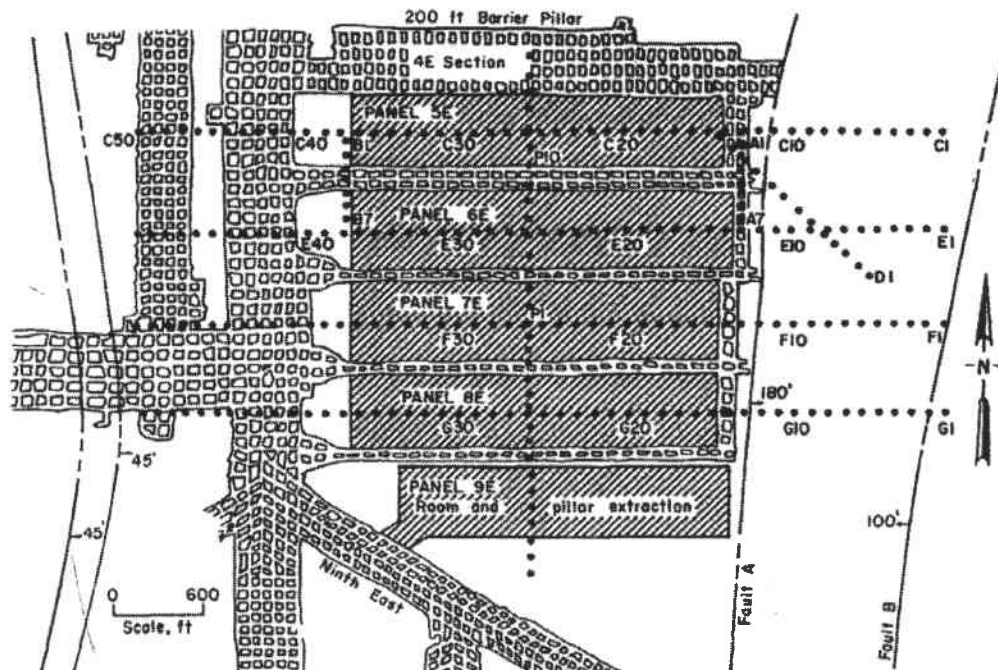
Figure 6. Subsidence monument locations above the USBM study site, East Mountain.
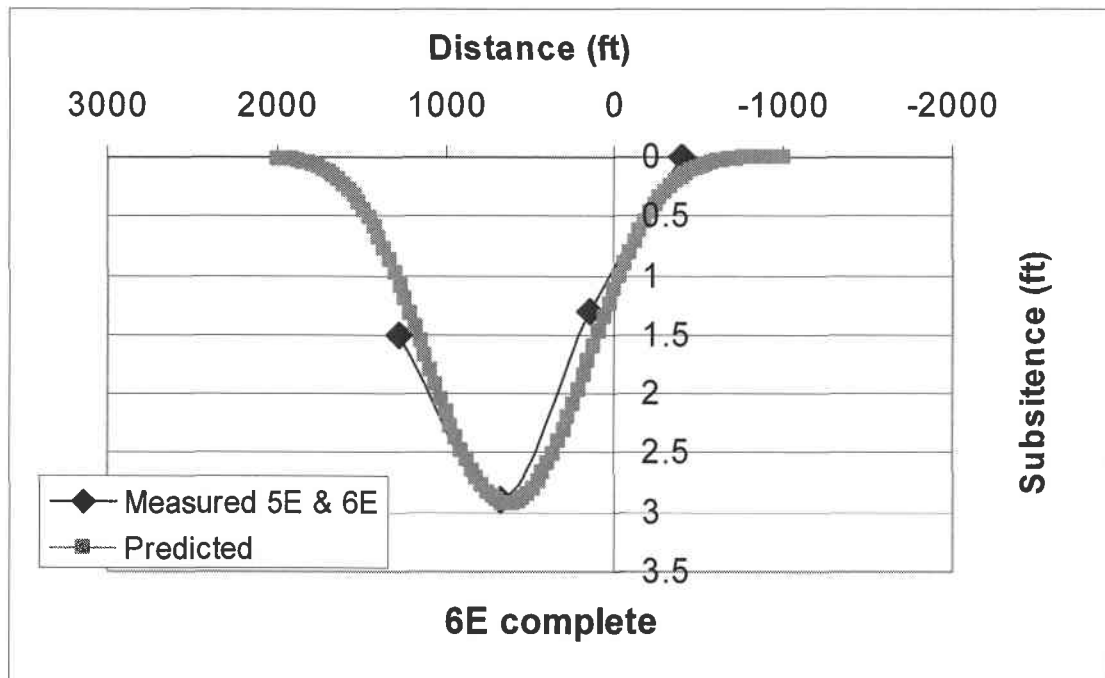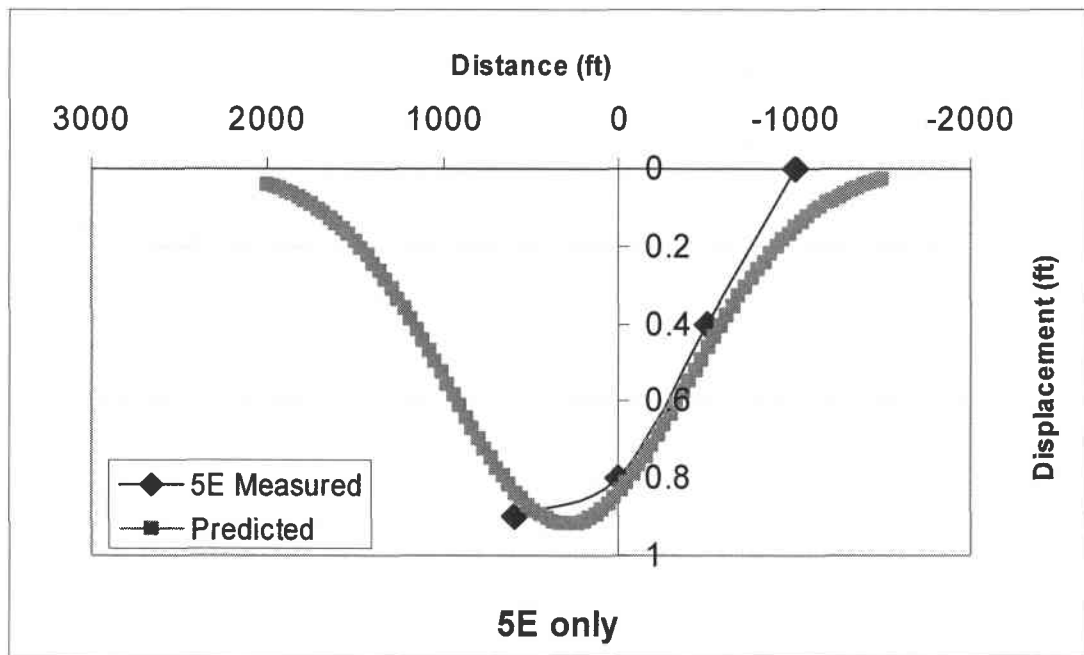
Figure 7. Compared measured and calculated subsidence after extraction of 5E and 6E panels.
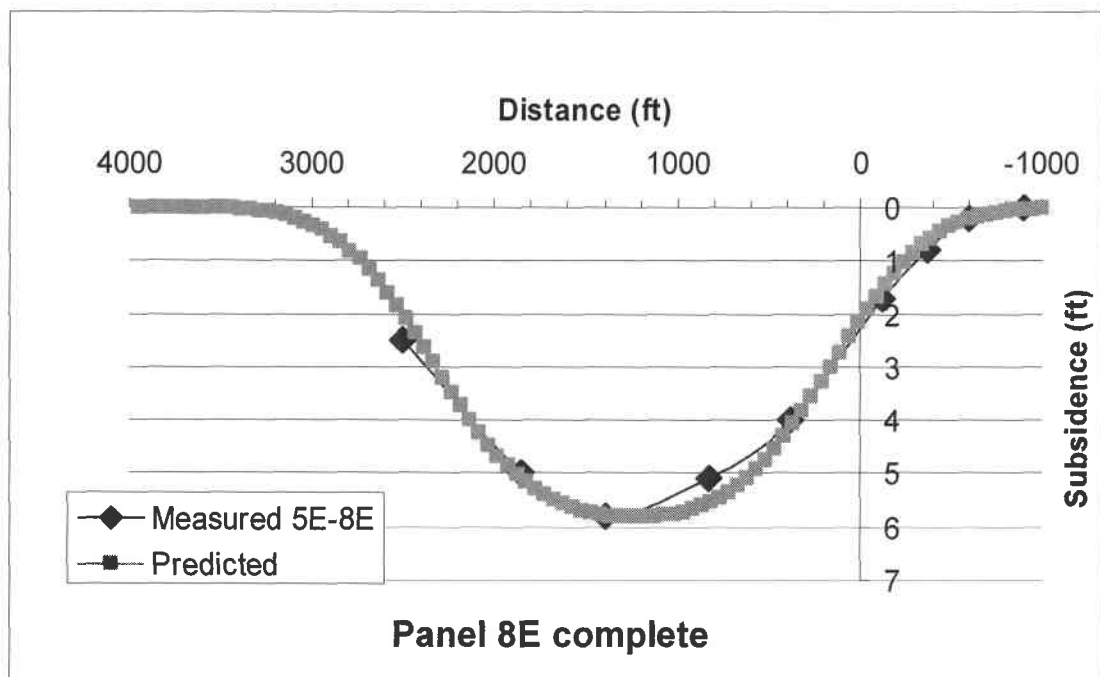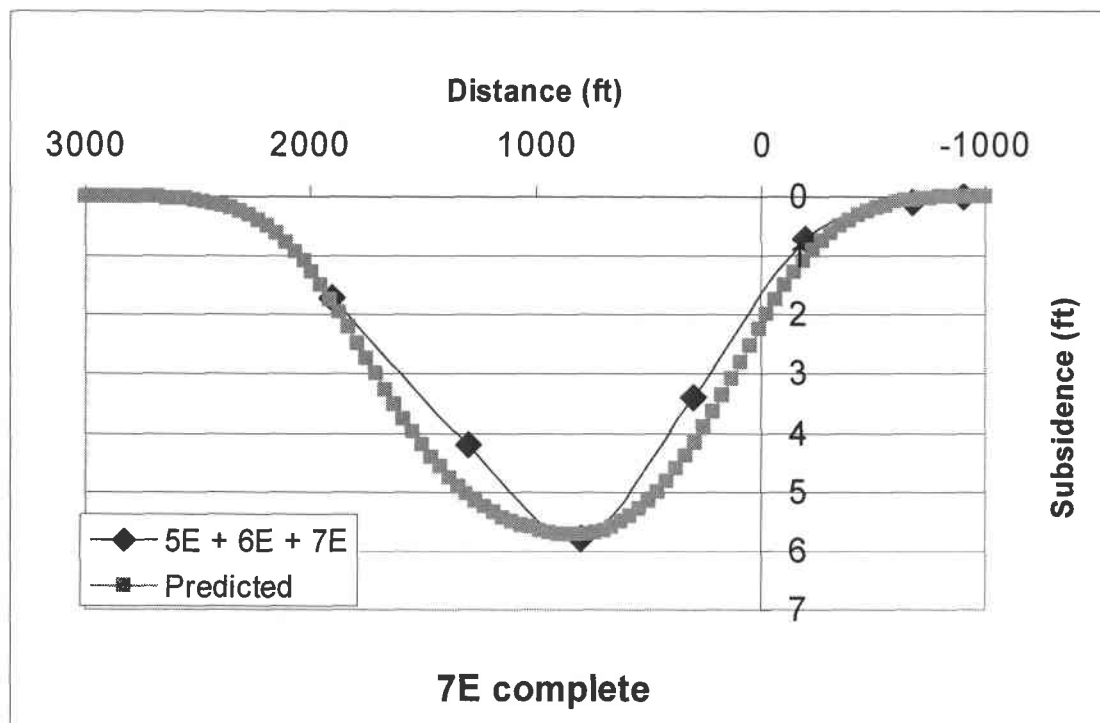
Figure 8. Compared measured and calculated subsidence after extraction of 7E and 8E panels.
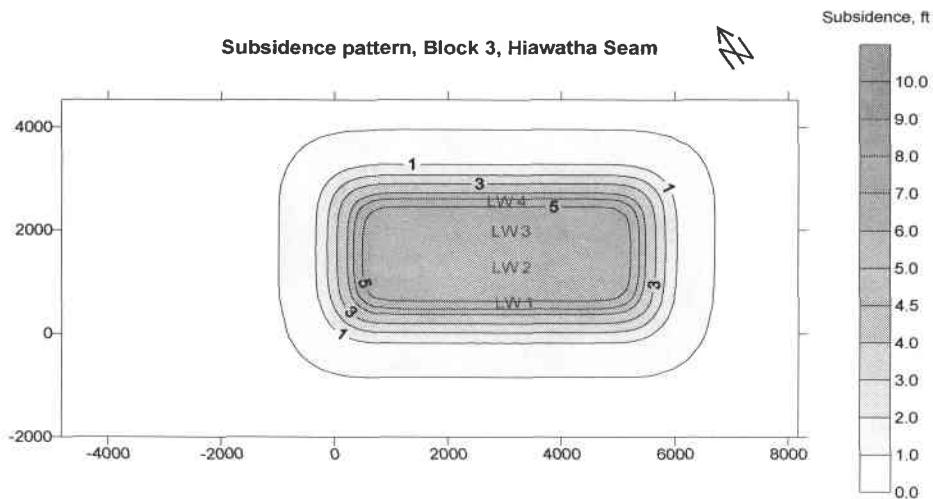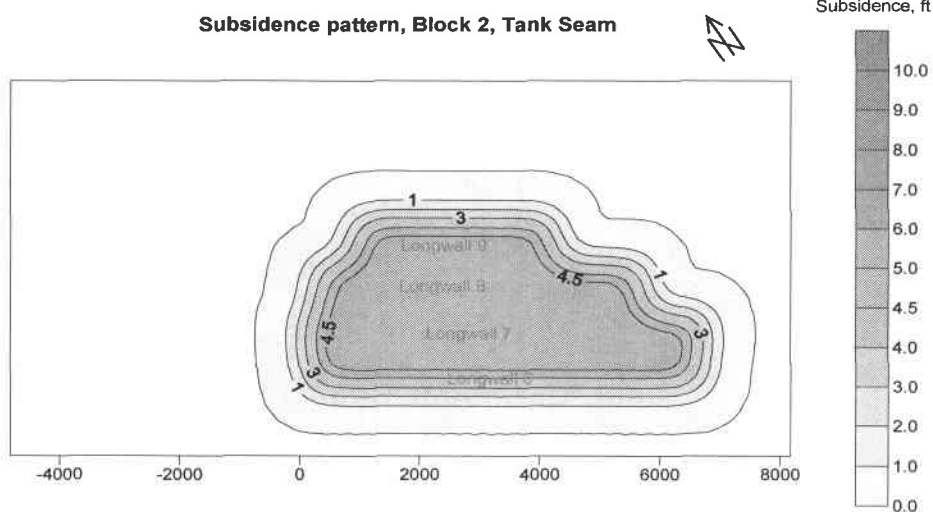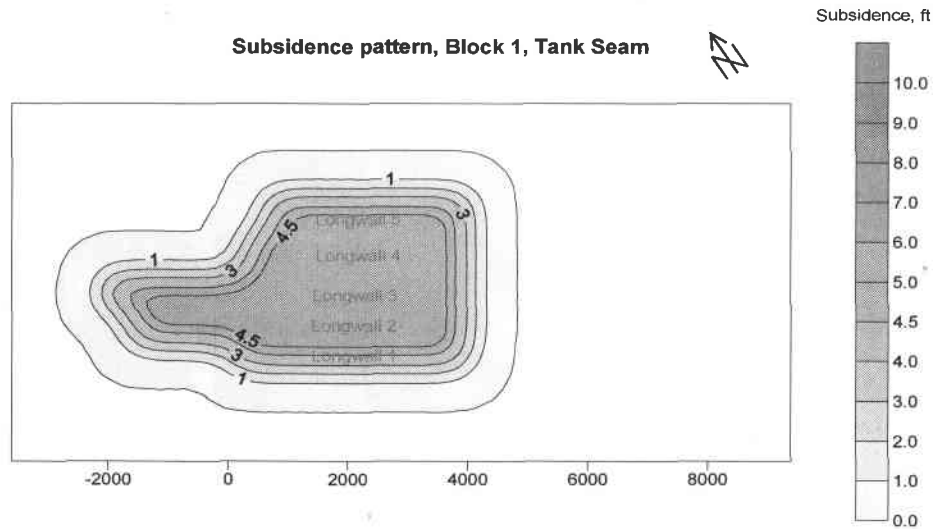
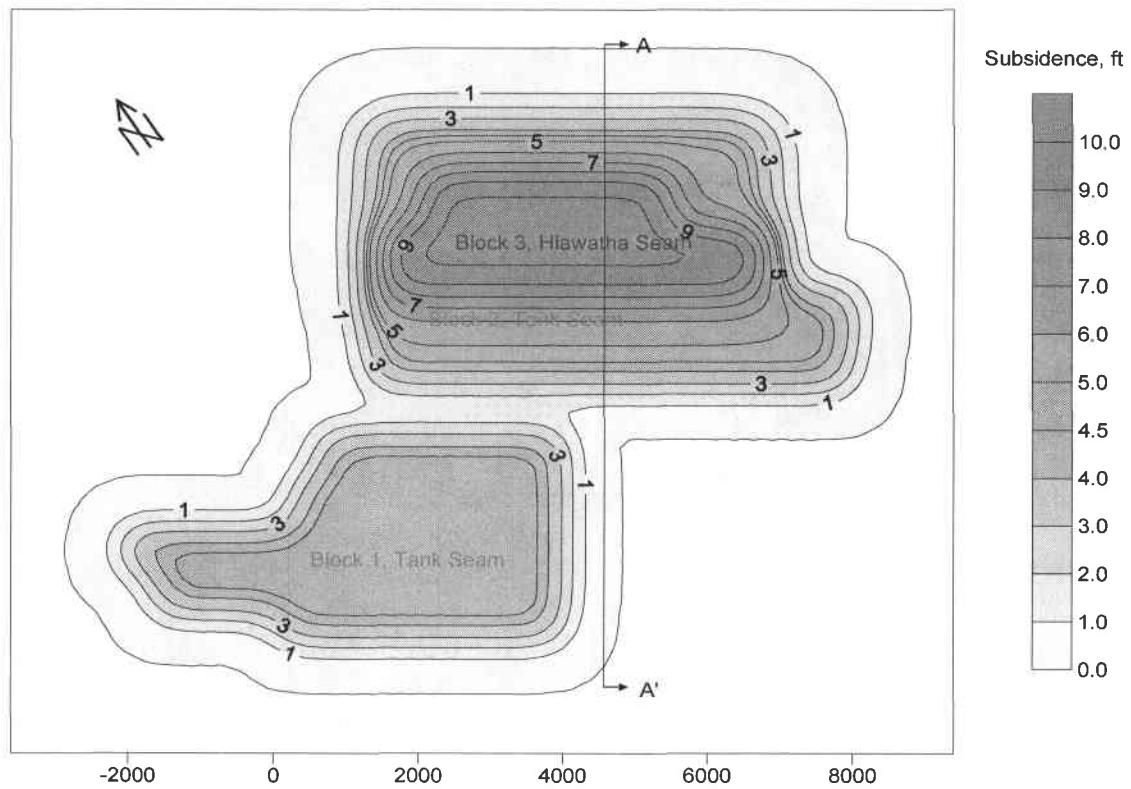Figure 9. Subsidence pattern over longwall blocks 1, 2 and 3.

Figure 10. Total subsidence pattern after the extraction of blocks 1 through 3.
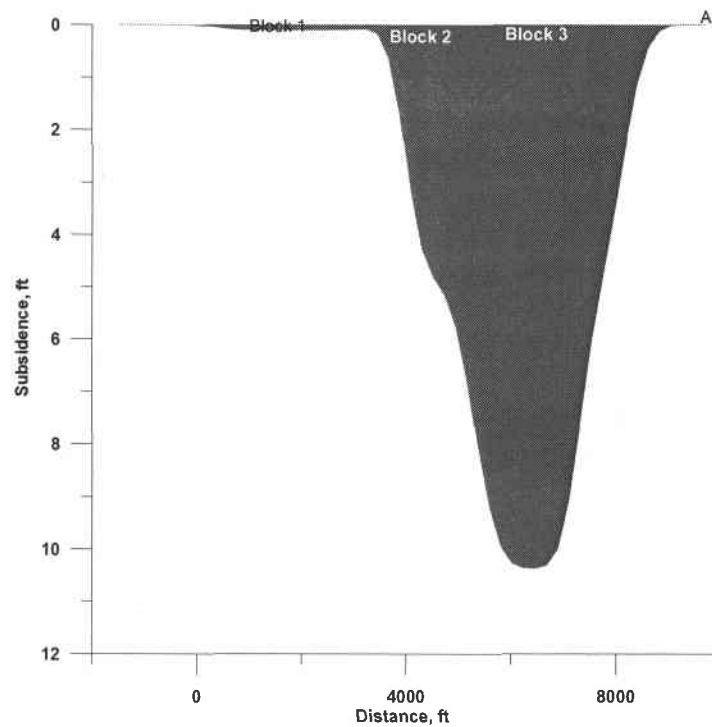

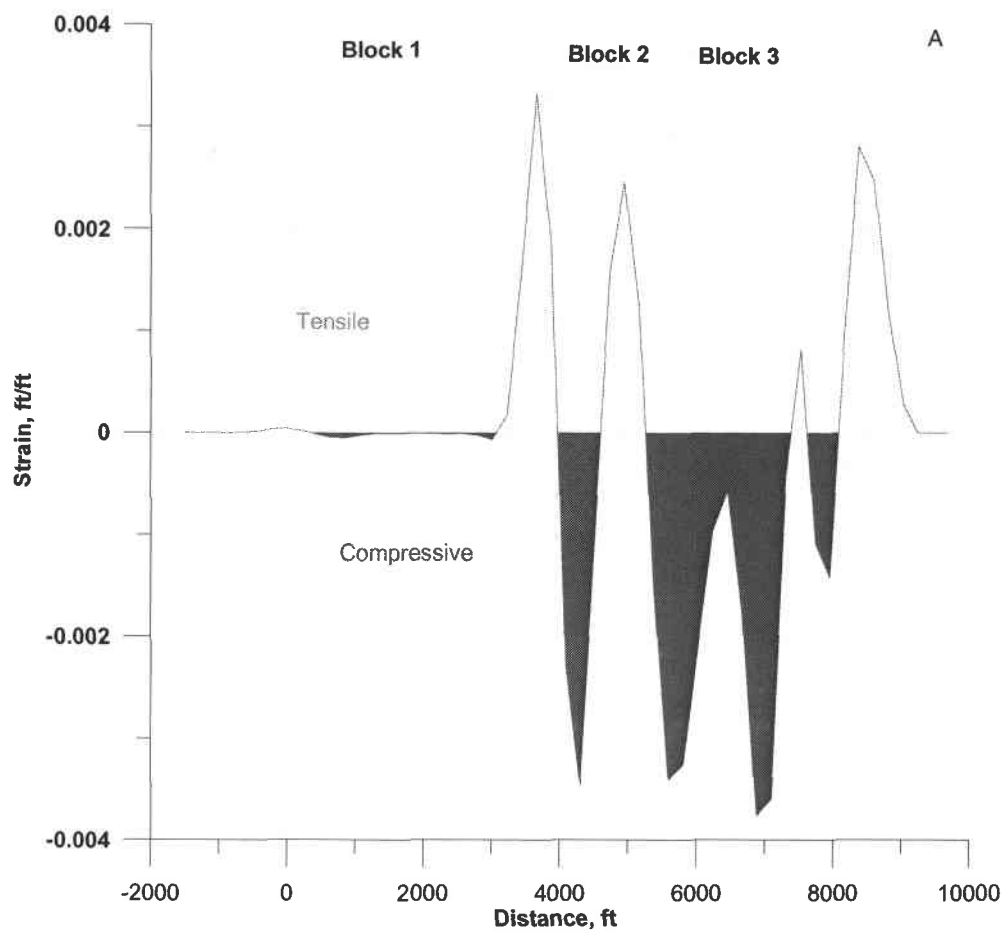Figure 11. Typical subsidence profile at location A.

Figure 12. Typical final strain profile at location A.

5.0 MONITORING PROGRAM

A subsidence-monitoring program should be implemented to verify the subsidence predicted in this study and to record any mining-induced damage to surface resources.

Subsidence monuments should be monitored by surveying a monument line across the first longwall block. For verification purposes, it would be desirable to locate the monument line near the center of this block. The monument spacing of 50-ft is recommended over the first longwall panel for detailed comparison to the predictions. The monument spacing may be increased to 250-ft over panels 2 through 5.

From such monitoring, site-specific angle of draw, subsidence factor, and tensile strains can be calculated resulting in predictive subsidence techniques for the Bear Canyon study area. However, the arrangement and location of the monument line or method of survey can vary according to site-specific conditions influenced by topography, roads, etc.

Measurements should include a precision level survey to measure vertical settlement and possibly a steel tape extensometer to measure horizontal strain. GPS methods have recently become available and used in many western U.S. operations successfully. Alternatively, aerial photographic methods used extensively at the neighboring Trail Mountain and East Mountain, may be used.

C.W. Mining has not observed surface cracking above the existing panels and thus does not foresee the need for detailed monitoring. USBM researchers report very few mining-induced cracks over the East Mountain (Dyni 1991; Fejes 1986). MTI has designed and analyzed surface monitoring programs over Colorado mines (Maleki and others 2006). In some shallow mines, geologic staff conducts an annual crack survey over active longwall panel areas. A visual inspection is deemed sufficient over the deeper mines. The survey data include crack location, orientation, horizontal length, and width. Based on these measurements, MTI recommends a limited monitoring program so that the presence of surface cracks (if any) can be verified.

References

Allgaier F.K. 1994. Surface subsidence over longwall panels in the western United States- Final results at the Deer Creek Mine, Utah. U. S. Bureau of Mines Information Circular 9194, 17 pp.

Dyni, R. C., 1991. Subsidence Resulting from Multiple-Seam Longwall Mining in the Western United States – A Characterization Study. USBM IC 9297.

Fejes, A., 1986, Surface Subsidence Over Longwall Panels in the Western United States, USBM Report of Investigations. IC 9099.

Karfakis, M. 1987. Chimney Subsidence over Abandoned Coal Mines. International Journal of Mining and Geological Engineering, V. 5, pp. 131-134.

MTI 2001, Report prepared by Maleki Technologies, Inc. to C.W. Mining entitled "Modeling of Castlegate Sandstone Escarpment Stability". July 2001, pp 19.

Maleki, H., R. Olson, D. Spillman, and M. Stevenson, 2003. Development of Geotechnical Procedures for the Analysis of Mine Seismicity and Pillar Designs, 22nd International Conference in Ground Control in Mining, Morgantown, WV, 2003.

Maleki, H., R. Heath, and G. Tetreault, 2001. Development of Guidelines for Determination of Maximum Economic Recovery, SME Transactions, Vol. 310, 161 pp.

Peng, S. S., 1992. Surface Subsidence Engineering, SME, 161 pp.

Peng, S. S., and Yi Luo, 1994. Comprehensive and Integrated Subsidence Monitoring, WV University, 64 pp.

SDPS, 2000. Surface Deformation Prediction System, VPI.

USBM 1983. SPASID, A Computer Program for Predicting Ground Movement Due to Underground Mining. USBM contract J02955031.

Maleki H, K. Fleck, C. Semborski and C Pollastro, 2000, Development of a Statistical Technique for Assessing Sandstone Escarpment Stability. 19th. International Conf. On Ground Control, WV university, 2000.

Maleki, H., 1988, Ground Response to Longwall Mining--A Case Study of Two-Entry Yield Pillar Evolution in Weak Rock. CO School of Mines Quarterly, vol. 83, no. 3, 1988.

Maleki, H., J. Owens, W. Howie, 1999, An Overview of Geomechanics Safety Research on Mobile Roof Supports. 17th International System Safety Conference, August 16-21, 1999, Orlando, FL.

Jones R.E. 1994. Investigation of Sandstone Escarpment Stability in the Vicinity of Longwall Mining Operations. M.S. Thesis, Department of Mining Engineering, University of Utah.

Singh, M. M., and S. Bhattacharya. 1984. Proposed criteria for assessing subsidence damage to renewable resource lands, Preprint No., 84-391. Presentation at SME meeting.

Maleki H., C. Stewart, and G. Hunt, 2006. Subsidence Characteristics of Bowie Mines, Colorado, Proceedings of Golden Rocks 2006, 50 years of Rock Mechanics, Colorado School of Mines.

Reynolds, M, 2006, personal communications regarding face support specifications and observed conditions above existing room-and-pillar panels in the Wild Horse Ridge reserve.